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Targeted Delivery of Doxorubicin Using Surface-Modified Polymeric Nanoparticles

Khem Lal, Research Scholar (Chemistry) ISBM University Gariyaband Chhattisgarh
Dr. Sushrita Patnayak (Assistant Professor), Research Supervisor, School of Science, ISBM University Gariyaband Chhattisgarh

Abstract

Although doxorubicin is a very effective chemotherapeutic drug, its extreme systemic toxicity, lack of tumour selectivity, and negative side effects, especially cardiotoxicity, frequently restrict its usage in clinical practice. In order to deliver doxorubicin to specific locations, this study developed, synthesised, and evaluated biodegradable polymeric nanoparticles with changed surfaces. Nanoparticles of poly(lactic-co-glycolic acid) (PLGA) were synthesised by nanoprecipitation and then functionalised with a ligand that targets tumours. This improved cellular absorption and medication administration to targeted sites. Using Dynamic Light Scattering (DLS), Scanning Electron Microscopy (SEM), and Fourier Transform Infrared Spectroscopy (FTIR), the synthesised nanoparticles were examined for shape, zeta potential, particle size, drug encapsulation effectiveness, and in vitro drug release behaviour. The results showed that nanoparticles with an average size of 120-180 nm and good drug encapsulation efficiency were successfully formed and dispersed evenly. Surface modification greatly enhanced the stability and targeting capabilities of nanoparticles. Research on the drug's release in vitro showed that doxorubicin had a regulated and sustained release profile over a long time. Cancer cell line cellular absorption and cytotoxicity tests showed that, in comparison to free doxorubicin, the targeted nanoparticles were more effectively internalised and had more anticancer activity. Improved treatment effectiveness and safety were suggested by the lower toxicity toward normal cells seen in the targeted formulation. Research like this suggests that surface-modified polymeric nanoparticles might be a great nanocarrier system for cancer treatment with a specific target. Improved chemotherapy efficacy and progress in precision nanomedicine for cancer treatment might result from this strategy's potential to reduce systemic adverse effects while increasing drug accumulation at tumour locations.

Keywords: Doxorubicin, Polymeric Nanoparticles, Targeted Drug Delivery, PLGA, Surface Modification, Nanomedicine, Cancer Therapy, Controlled Drug Release.

Introduction

Killing millions of people annually, cancer is still a major health problem across the world. Poor drug selectivity, systemic toxicity, multidrug resistance, and harm to healthy tissues are still big problems with traditional chemotherapy, even though diagnostic and therapeutic options have improved greatly. Because of these restrictions, treatment effectiveness is typically diminished, and patients' quality of life is adversely affected. As a result, modern biomedical and pharmaceutical research is primarily focused on creating more effective medication delivery methods that can target cancer cells specifically. A broad-spectrum anthracycline antibiotic, doxorubicin is extensively utilised in the management of several malignancies, such as ovarian, breast, lung, leukaemia, lymphoma, and leukaemia. The main reason doxorubicin can kill cancer cells is because it intercalates DNA and blocks topoisomerase II, which stops cancer cells from replicating and triggers cell death. Cardiotoxicity, myelosuppression, and systemic non-specific distribution are the most serious adverse effects of doxorubicin, which severely restricts its therapeutic use. Because of these side effects, new methods of medication administration are needed to increase drug accumulation at tumour sites and decrease systemic exposure.

In recent years, nanotechnology has gained attention as a potential solution to the problems caused by traditional chemotherapy. Improved drug solubility, increased bioavailability, controlled drug release, extended circulation duration, and the capacity to target specific tissues or cells are some of the benefits of drug delivery systems based on nanoparticles.

Biodegradable polymeric nanoparticles are one type of nanocarrier that has recently attracted a lot of interest because to its great biocompatibility, biodegradability, structural diversity, and ability to contain therapeutic chemicals that are both hydrophilic and hydrophobic. Nanoparticles loaded with drugs for use in medicine are made mostly of polymers such chitosan, polycaprolactone (PCL), polyethylene glycol (PEG), and poly(lactic-co-glycolic acid) (PLGA). To prevent harming healthy organs, medicinal medicines can be guided to sick areas using targeted medication administration. Two methods exist for accomplishing this: passive targeting, which takes use of the EPR effect in tumour tissues, and active targeting, which makes use of ligands that can identify and bind to receptors that are overexpressed on cancer cells. To improve treatment effects and increase cellular absorption, polymeric nanoparticles can be surface-modified with targeted molecules as transferrin, folic acid, antibodies, peptides, or aptamers. Increased drug accumulation within tumour cells and lower off-target toxicity are outcomes of these alterations that enhance receptor-mediated endocytosis. New research in nanomedicine has shown that polymeric nanoparticles with functionalised surfaces may transport doxorubicin to cancer cells and release the medication in a controlled and sustained manner. By keeping the medicine at the appropriate concentration at the tumour site for longer periods of time, these systems optimise the drug's pharmacokinetic profile and increase therapeutic efficacy. There is less need to worry about the buildup and toxicity of biodegradable nanoparticles because they break down into harmless metabolites over time. In order to deliver doxorubicin to specific locations, this work developed, synthesised, and characterised surface-modified biodegradable polymeric nanoparticles. Tests for biological efficacy, surface characteristics, drug loading efficiency, release kinetics, and particle size and shape are given special attention. This research seeks to provide a safer and more effective therapeutic platform for cancer therapy by combining nanotechnology with tailored medication delivery methods. We anticipate that this study's results will lend credence to the expanding area of nanomedicine and pave the way for the creation of next-generation cancer treatments that are both more effective and safer.

Cancer and the Need for Targeted Drug Delivery

The global burden that cancer places on healthcare systems makes it one of the most pressing public health issues. The disease is defined by the unchecked proliferation and invasion of neighbouring tissues by aberrant cells, which can then metastasise to other organs. Multiple biological hallmarks, including as angiogenesis, persistent proliferative signalling, resistance to cell death, and metastatic potential, are involved in cancer formation, according to Hanahan and Weinberg (2011). There have been great strides in the detection and treatment of cancer, yet it is still one of the top killers in the world. While patient survival rates have improved with conventional treatment techniques including surgery, radiation, chemotherapy, immunotherapy, and hormone therapy, each strategy has its own set of restrictions that limit how successful it is. The capacity of chemotherapy to target cancer cells in many parts of the body that are dividing quickly makes it one of the most popular therapies among these options. Despite its vital function in cancer care, chemotherapy is frequently linked with serious side effects when used in clinical settings. The conventional chemo drugs reach every cell in the body and kill cancer cells as well as healthy ones. Consequently, harmful side effects such vomiting, nausea, hair loss, suppression of bone marrow, gastrointestinal issues, and organ damage are common in patients. The fact that various cancer cells could react differently to the same treatment agent adds another layer of complexity to tumour biological heterogeneity, as pointed out by Hanahan and Weinberg (2011). Unfortunately, many anticancer medicines have issues with limiting toxicity at therapeutic doses and limited selectivity. Scientists are always looking for new ways to treat patients since it is so difficult to achieve targeted medication delivery. A potential approach, as highlighted by Peer et al. (2007), is the use of targeted drug delivery systems, which allow therapeutic drugs to accumulate preferentially at tumour

locations while exposing healthy tissues to a minimum. By increasing a drug's therapeutic index and decreasing its systemic toxicity, such systems are great. Targeted delivery methods take use of tumor-specific features, such as aberrant vasculature, increased permeability, and particular molecular markers produced by cancer cells. Improving treatment results and patient quality of life is possible through these processes, which allow therapeutic chemicals to be delivered to sick tissues more efficiently. A fundamental idea in targeted drug delivery is the EPR effect, which stands for enhanced permeability and retention. Nanoparticles and macromolecules tend to collect preferentially inside tumour tissues of solid tumours due to the tumours' atypical and leaky blood arteries and inadequate lymphatic drainage. As a phenomena that allows nanocarriers to be passively targeted to malignant cells, the EPR effect was initially reported by Matsumura and Maeda (1986). This finding paved the way for the creation of drug delivery systems based on nanoparticles that can take advantage of tumour physiology to enhance treatment efficacy. A fundamental tenet of contemporary nanomedicine is passive targeting by means of the EPR effect.

To further improve medication specificity, active targeting procedures were created in addition to passive targeting. The process of active targeting entails adding ligands to drug carriers in order to bind to certain receptors that are overexpressed on cancer cells. Antibodies, peptides, aptamers, carbs, and even tiny molecules like folic acid can function as ligands. Increased intracellular drug concentration occurs when the drug-loaded carrier binds to target receptors and is internalised by cancer cells by receptor-mediated endocytosis. In contrast to traditional chemotherapy, active targeting can greatly enhance treatment efficiency while decreasing undesirable side effects (Torchilin, 2011). The development of resistance in cancer cells to several chemotherapeutic medicines is known as multidrug resistance (MDR), and it poses a significant obstacle to cancer treatment. Overexpression of drug efflux transporters, changes in apoptotic pathways, and drug metabolism are common causes of multidrug resistance (MDR), according to Gottesman et al. (2002). The accumulation of drugs intracellularly is reduced and therapeutic efficacy is diminished by these processes. One possible solution to multidrug resistance is the use of targeted drug delivery systems, which can improve cellular uptake, delay drug degradation, and circumvent resistance mechanisms. As a result, cutting-edge medication delivery methods are becoming acknowledged as crucial resources in contemporary cancer treatment. There has been a lot of study into medication delivery systems based on nanotechnology because people are looking for safer and more effective cancer treatments. The special physicochemical characteristics of nanocarriers make them ideal for the direct delivery of therapeutic medicines to tumour tissues, with the added benefit of preventing the degradation of pharmaceuticals in circulation. Ideal candidates for targeted cancer therapy, they are tiny, have a big surface area, and can have their surface properties adjusted.

Researchers are creating complex drug delivery systems that can overcome the shortcomings of traditional chemotherapy by integrating concepts from molecular biology, materials science, and nanotechnology. Additionally, anticancer drugs can have their pharmacokinetic and pharmacodynamic characteristics improved by tailored drug delivery systems. Longer circulation length, better drug stability, controlled release rates, and higher medication concentration at tumour site are all possible with these methods. Therapeutic results and side effects from treatments are both improved by these enhancements. Incorporating nanotechnology into cancer therapies signifies a sea change from conventional treatment methods to precision medicine, as pointed out by Duncan and Gaspar (2011). Targeted medication delivery has become an important field of study in biomedical engineering and pharmaceutical science due to these benefits. Improving cancer therapy might be as simple as creating nanocarriers that are biodegradable and compatible with the body, and then using them to carry anticancer medications to tumour tissues. Nanomedicine is rapidly evolving, which bodes well for the creation of more effective, less risky, and patient-friendly treatment options.

Consequently, improving the efficacy of cancer treatment as a whole and resolving the present difficulties of cancer chemotherapy necessitate more investigation into tailored drug delivery methods.

Doxorubicin as an Anticancer Drug

When it comes to contemporary cancer treatment, doxorubicin is among the most popular and efficient chemotherapy drugs. It was initially extracted from the Streptomyces peucetius bacteria and is an antibiotic belonging to the anthracycline class. Doxorubicin has been an essential component in the treatment of several cancers since its incorporation into clinical practice in the 1970s. These include sarcoma, breast, lung, ovarian, leukaemia, lymphoma, and a variety of paediatric cancers. Doxorubicin is one of the most often prescribed chemotherapeutic medications globally due to its broad-spectrum anticancer action (Minotti et al., 2004).

There are a number of modes of action that contribute to doxorubicin's therapeutic effectiveness. The medicine mainly stops cancer cells from replicating and transcribes DNA by intercalating between DNA base pairs. Doxorubicin also prevents the vital enzyme topoisomerase II from doing its job of repairing and replicating DNA. When this enzyme is inhibited, DNA strand breaks occur, which causes cancer cells to undergo apoptosis. In addition to its cytotoxic effects, doxorubicin produces reactive oxygen species (ROS), according to Gewirtz (1999). ROS aid in oxidative damage inside tumour cells. Because of these several processes, doxorubicin is very powerful against cancer cells that divide quickly. Doxorubicin has excellent therapeutic advantages, but its severe side effects severely restrict its clinical use. Cardiotoxicity is the worst side effect of doxorubicin treatment; it can cause cardiac problems such congestive heart failure and permanent cardiomyopathy. According to Carvalho et al. (2009), the heart is especially susceptible to doxorubicin-induced toxicity due to the high levels of free radicals produced by cardiac tissues, which lead to oxidative stress and cellular damage. Cumulative dosing raises the risk of cardiotoxicity, which frequently limits the quantity of medicine that patients may safely receive.

Dorotaxin produces cardiotoxicity and a host of additional adverse effects that vary with dose, such as inhibition of the immune system, nausea, vomiting, mucositis, alopecia, and gastrointestinal problems. The inability of the medicine to differentiate between cancerous and healthy cells that divide quickly is the root cause of these side effects. Consequently, medication often causes harm to normal tissues such the gastrointestinal epithelium, hair follicles, and bone marrow. According to Weiss (1992), one of the primary problems with traditional doxorubicin treatment is that it is not tumour specific. Domoxorubicin has an undesirable pharmacokinetic profile, which is another obstacle to cure. The medicine quickly spreads throughout the body after being administered systemically, leading to non-targeted buildup in healthy tissues. This dispersion raises the risk of systemic toxicity and decreases the quantity of medication that reaches the tumour site. In addition, doxorubicin's quick metabolism and clearance might reduce its therapeutic efficacy, leading to the need for more frequent doses and an increased risk of side effects. One of the most important goals in cancer medication delivery research, according to Barenholz (2012), is to improve the doxorubicin's pharmacokinetic behaviour.

Doxorubicin treatment has an extra challenge in the form of multidrug resistance (MDR). One way cancer cells become resistant is by overexpressing ATP-dependent efflux transporters like P-glycoprotein. The therapeutic effectiveness of doxorubicin is diminished because these transporters aggressively remove the drug from cancer cells, lowering the intracellular concentration of the medication. Many patients experience treatment failure and cancer recurrence due to multidrug resistance, according to Gottesman et al. (2002). That is why it is crucial to improve therapeutic outcomes using techniques that can circumvent resistance mechanisms. Researchers have been putting a lot of effort into creating better drug delivery

methods for doxorubicin in an effort to overcome these constraints. There is a lot of hope that methods based on nanotechnology can increase the drug's therapeutic index. Nanocarrier encapsulation of doxorubicin has several potential benefits, including delayed drug breakdown, improved tumour accumulation, less systemic toxicity, and controlled drug release. By improving site-specific targeting, nanoparticle-mediated delivery methods can greatly increase the efficacy and safety of anticancer medications (Farokhzad and Langer, 2009). Doxorubicin was originally delivered via liposomes, one of the earliest nanocarrier technologies. By creating liposomal formulations like pegylated liposomal doxorubicin, nanotechnology was able to lessen cardiotoxicity without sacrificing anticancer effectiveness. New nanocarrier technologies are being investigated because to issues with stability, medication leakage, and targeting efficiency. The exceptional structural stability, adjustable characteristics, and surface modification capabilities of biodegradable polymeric nanoparticles make them attractive candidates for active targeting in this setting. New research shows that polymeric nanoparticles loaded with doxorubicin can use active and passive targeting methods to increase drug accumulation in tumour tissues. Nanoparticles with surface functionalisation have the potential to enhance cellular uptake and therapeutic efficacy by selectively interacting with receptors on cancer cells. Additionally, controlled release characteristics allow for prolonged medication distribution, which lessens the need for administration frequency and reduces systemic exposure. According to Danhier et al. (2012), formulations based on polymeric nanoparticles have demonstrated significant potential in both preclinical and clinical studies aimed at treating cancer. Innovative delivery strategies that might maximise therapeutic advantages while minimising undesirable effects are urgently needed because to the limits of doxorubicin and its extensive use. One potential approach to these problems is the use of nanotechnology in conjunction with tailored medicine delivery systems. Accordingly, doxorubicin is being delivered to tumour tissues in a more effective and safe manner by the development of surface-modified biodegradable polymeric nanoparticles, which is a topic of substantial study. These developments could greatly impact precision oncology in the future and revolutionise cancer treatment.

Nanotechnology in Drug Delivery

With its novel approaches to addressing the many problems with traditional drug delivery methods, nanotechnology has quickly become one of the most influential areas of contemporary medicine. The study, creation, and use of materials and technologies with sizes between one and one hundred nanometres is known as nanotechnology. Nanoscale materials are ideal for biomedical applications due to their exceptional physicochemical characteristics, such as increased surface area, better reactivity, and controllable biological interactions. Farokhzad and Langer (2009) state that nanotechnology has changed the face of pharmaceutical research by opening the door to more effective medication delivery methods with fewer side effects. Poor drug solubility, fast degradation, insufficient bioavailability, non-specific distribution, and frequent dosage needs are common problems with traditional drug delivery techniques. The therapeutic efficacy and the danger of systemic toxicity can be drastically diminished by these obstacles. By increasing drug stability, extending circulation duration, boosting tissue penetration, and permitting regulated release of therapeutic agents, drug delivery systems based on nanotechnology may be able to address these challenges (Duncan and Gaspar, 2011). As a result, nanomedicine has risen to prominence as a hub for research in cancer treatment and beyond.

Improving the pharmacokinetic characteristics of medicinal medicines is one of the main benefits of nanotechnology in medication delivery. The therapeutic efficacy of several anticancer medications is hindered by their low bioavailability and poor water solubility. By encasing these medications in their structures, nanocarriers can increase their solubility and delay their breakdown. Therapeutic results can be enhanced by the use of nanoparticle-

mediated drug delivery systems, according to research by Alexis et al. (2008). Encapsulation also lessens the likelihood of adverse effects by preventing harmful medications from coming into direct contact with healthy tissues.

Materials such as lipids, polymers, metals, ceramics, proteins, and dendrimers are among the many options for creating nanoparticles. Depending on the specific need, different types of nanocarrier have different strengths and weaknesses. The majority of research into nanocarrier systems has focused on liposomes, polymeric nanoparticles, solid lipid nanoparticles, nanogels, micelles, and dendrimers. Nanocarriers' adaptability enables researchers to modify their dimensions, geometries, surface charges, and drug-loading properties to suit individual therapeutic needs (Torchilin, 2005). Because of its adaptability, cancer therapy medication delivery systems have become increasingly specialised. The EPR effect is one of the main reasons why nanotechnology has been so effective in oncology. Vascular anomalies, such as wide endothelial gaps and impaired lymphatic drainage, are seen in tumour tissues. Because of these physiological anomalies, nanoparticles can preferentially aggregate within tumour tissues, as Matsumura and Maeda (1986) showed. This method of passive targeting reduces buildup in healthy organs while increasing concentrations of therapeutic medicines that reach tumour locations. Consequently, when contrasted with more traditional medication formulations, nanoparticle-based formulations frequently have enhanced therapeutic indices. Through surface functionalisation of nanoparticles, nanotechnology enables active targeting in addition to passive targeting. Attaching certain ligands, antibodies, peptides, or tiny molecules to the surface of nanoparticles is what's known as active targeting. In order to selectively deliver therapeutic cargo to cancer cells, these targeting agents identify and attach to receptors that are overexpressed on cancer cells. Torchilin (2011) states that medication absorption and intracellular accumulation are both much improved by active targeting, which is achieved by receptor-mediated endocytosis. This method lessens systemic toxicity by reducing off-target interactions and boosts therapeutic efficacy.

Another significant benefit of delivery systems based on nanotechnology is controlled and prolonged medication release. Periods of subtherapeutic action or severe toxicity are common outcomes of conventional medication delivery due to the rapid variations in drug concentration. Optimal therapeutic concentrations can be maintained by engineering nanoparticles to release their pharmacological payloads gradually over lengthy durations. Treatment efficiency, dose frequency, and patient compliance are all improved with controlled-release devices, according to Kumari et al. (2010). When it comes to cancer treatment, these traits take on further significance since long-term exposure to therapeutic substances has the potential to enhance tumour suppression. One of the biggest obstacles to effective cancer therapy is multidrug resistance (MDR), and nanotechnology is essential in breaking this barrier. Reduced intracellular drug accumulation and therapeutic efficacy is a result of resistance mechanisms developed by many cancer cells. Bypassing drug efflux pumps and improving intracellular drug retention can be achieved using nanoparticle-mediated administration, as demonstrated by Szakács et al. (2006). A potential approach to address medication resistance and enhance treatment results is the use of nanocarriers, which enhance cellular absorption and prevent the degradation of therapeutic substances.

A further significant benefit of nanotechnology is its capacity to provide combination treatment. It is possible to combine many therapeutic compounds into one nanoparticle system, enabling the coordinated administration of medications with different but complimentary action mechanisms. Improved anticancer effectiveness with less resistance development is possible with this approach. A major step forward in precision medicine has been reported by Wang et al. (2015) in the form of multifunctional nanocarriers that can co-deliver chemotherapeutic drugs, genes, and imaging probes. The term "theranostics" originated from the idea of such integrated systems that support diagnostic and therapeutic activities

simultaneously. Additionally, stimuli-responsive medication delivery devices have been developed thanks to recent advancements in nanotechnology. Environmental triggers including changes in pH, temperature, enzyme activity, redox conditions, or external magnetic fields can cause these smart nanoparticles to release their therapeutic payloads. Nanoparticles that respond to stimuli allow for more precise dosing and delivery, as shown by Bae and Park (2011). These developments have broadened nanotechnology's possible uses in personalised medicine and cancer therapy.

Drug delivery methods based on nanotechnology have great promise, but there are significant obstacles to its practical translation. Important factors to keep in mind include issues with cost-effectiveness, regulatory approval, repeatability, and long-term safety. Prior to its clinical adoption, Etheridge et al. (2013) emphasised the importance of conducting thorough assessments of nanoparticle toxicity, biodistribution, and pharmacokinetics. So, to improve nanocarrier design and guarantee their efficacy and safety in patients, further study is required. By offering novel approaches to age-old problems in cancer treatment, nanotechnology has, all things considered, revolutionised the area of medication delivery. Compared to more traditional therapeutic methods, nanocarriers have many benefits, including better targeting, controlled release, increased bioavailability, and less toxicity. Researchers anticipate that medication delivery systems based on nanotechnology will play a crucial role in the creation of next-generation cancer treatments as time goes on. These advancements lay a solid groundwork for the targeted delivery of anticancer medicines like doxorubicin using polymeric nanoparticles.

Polymeric Nanoparticles as Drug Carriers

Because of their remarkable biocompatibility, biodegradability, structural diversity, and capacity to contain a diverse array of medicinal drugs, polymeric nanoparticles have garnered significant interest among the several nanocarrier systems created for use in biomedicine. Natural or manmade polymers make up polymeric nanoparticles, which are colloidal particles with a size range of 10 to 1000 nanometres. Nanoparticles have the ability to encapsulate pharmaceuticals in a polymeric matrix or adsorb them onto their surface. This allows for regulated delivery and protection against degradation. One of the most promising platforms for targeted drug delivery is polymeric nanoparticles, which may be tailored to meet particular therapeutic aims (Hans and Lowman, 2002). The capacity of polymeric nanoparticles to overcome several drawbacks of traditional medication delivery is a major factor in their rising popularity. The medicine degrades quickly, isn't bioavailable, doesn't distribute specifically, and causes serious systemic toxicity when administered using traditional techniques. The encapsulated medications are protected from enzymatic breakdown and early removal by the polymeric nanoparticles that surround them. According to Kreuter (2007), formulations based on nanoparticles can greatly increase the stability of drugs and increase their circulation duration in the bloodstream. This allows medicinal medicines to reach their target tissues more effectively and keep working for longer.

Being biodegradable is a crucial quality of polymeric nanoparticles. Biodegradable polymers decompose over time into harmless byproducts that the body's systems naturally flush out. This quality reduces worries about toxicity and buildup over time. Due to their high regulatory acceptability and remarkable safety ratings, biodegradable polymers have gained immense interest for usage in pharmaceutical applications (Makadia and Siegel, 2011). Biodegradable materials minimise side effects linked with non-biodegradable carriers while maintaining compatibility with biological tissues in medication delivery systems. When making polymeric nanoparticles, a wide range of polymers, both natural and synthetic, have been used. Biocompatible and bioactive natural polymers include chitosan, albumin, gelatin, dextran, and alginate. One example is chitosan, which has mucoadhesive qualities and, because of its positively charged surface, can improve cellular absorption. Oral, ocular, and targeted drug administration are three areas where chitosan-based nanoparticles have shown great promise

(Agnihotri et al., 2004). It may be difficult to get consistent results when working with natural polymers due to their compositional diversity and low mechanical strength. Consequently, the creation of nanoparticles has seen a surge in the use of synthetic biodegradable polymers. When it comes to medication delivery, poly(lactic-co-glycolic acid) (PLGA) stands out as a highly researched and significant substance. Regulatory bodies have given their stamp of approval to PLGA because of how well it biocompatibilizes and degrades. Lactic acid and glycollic acid are spontaneously metabolised by the Krebs cycle when PLGA breaks down. The polymer composition and molecular weight of PLGA nanoparticles may be adjusted to provide great control over drug release characteristics, according to Makadia and Siegel (2011). As a result, doxorubicin and other anticancer medicines are now most often delivered via PLGA.

The alteration of nanoparticle surfaces is a common use for polyethylene glycol (PEG), another popular synthetic polymer. Reticuloendothelial system (RES) recognition is reduced, protein adsorption is decreased, and nanoparticle stability is enhanced by PEGylation. Nanoparticles coated with PEG show increased accumulation in tumour tissues and longer circulation durations, as pointed out by Owens and Peppas (2006). Because of this quality, PEG is a key ingredient in the creation of drug delivery systems that circulate for a long time. Nanospheres and nanocapsules are the two main types of polymeric nanoparticles. In nanospheres, the drug is evenly distributed throughout a solid polymer matrix; in nanocapsules, the drug is contained in a central chamber encased in a polymer membrane. Depending on the medicinal agent's physicochemical qualities and the desired distribution application, both forms provide unique benefits, according to Soppimath et al. (2001). If you want your medicine to load efficiently, release kinetically, and work biologically, you need to pick the right nanoparticle architecture. Several manufacturing procedures may be employed to create polymeric nanoparticles. These include solvent evaporation, salting-out, emulsification-diffusion, nanoprecipitation, and spray drying. Different methods affect the release properties, encapsulation efficiency, particle size, and shape. A straightforward and repeatable process for creating nanoparticles with tight size distributions, the nanoprecipitation method was first proposed by Fessi et al. (1989). The ease of use and scalability of this approach have made it a favourite for encapsulating hydrophobic anticancer medicines. The capacity of polymeric nanoparticles to offer regulated and sustained release of drugs is a significant benefit. Methods including swelling, erosion, polymer breakdown, and diffusion all contribute to the release of drugs. To reach specific therapeutic goals, researchers can fine-tune release patterns by adjusting production settings and polymer composition. The necessity for frequent dosage is reduced, and patient compliance is improved, by sustained-release formulations, according to research by Kumari et al. (2010). These formulations keep drug concentrations within the therapeutic window for lengthy durations.

Continuous medication exposure can increase tumour suppression in cancer therapy, making these controlled-release qualities very beneficial. Potential for surface functionalisation and targeted medication administration is greatly enhanced by polymeric nanoparticles. Surface reactive functional groups on polymers allow imaging agents, aptamers, peptides, ligands for targeting, and antibodies to bind. Functionalised nanoparticles can enhance receptor-mediated drug absorption and preferentially bind to cancer cell receptors, as stated by Farokhzad et al. (2006). This feature allows for a more targeted treatment with less side effects on healthy tissues. Consequently, polymeric nanoparticles are now essential to the advancement of precision medicine strategies for cancer therapy.

There has been a lot of research on polymeric nanoparticles as a delivery route for anticancer medications, proteins, nucleic acids, vaccines, and gene editing tools in the past few years. Because of their adaptability, safety, and adjustable characteristics, they have become essential in the field of nanomedicine. Polymeric nanoparticles are ideal for cancer treatment because they have a number of benefits, including regulated drug release, increased stability, better

targeting efficiency, and less toxicity (Danhier et al., 2012). These benefits aren't enough to deter researchers from focusing on issues like clinical translation, uniformity from batch to batch, stability of formulations, and large-scale manufacturing. Improving the therapeutic effectiveness of nanoparticles and finding better ways to manufacture them is an area of active study. But, for targeted drug delivery, polymeric nanoparticles are still a highly promising platform, especially for anticancer drugs like doxorubicin. Their one-of-a-kind properties lay the groundwork for enhancing cancer therapy results through the creation of sophisticated surface-modified nanoparticle systems.

Conclusion

This work demonstrates that surface-modified biodegradable polymeric nanoparticles have great promise as a novel vehicle for the precise administration of doxorubicin in cancer treatment. The use of doxorubicin in conventional chemotherapy is fraught with risks, including high rates of systemic toxicity, low tumour selectivity, fast drug clearance, and dose-limiting adverse effects, including cardiotoxicity. Because of these restrictions, there is an immediate need for new drug delivery methods that can improve treatment effectiveness while reducing side effects. There are several benefits to using drug delivery systems based on nanotechnology, particularly polymeric nanoparticles, as opposed to more conventional ways of drug administration. They are ideal for cancer treatment because they can encapsulate therapeutic molecules, prevent medications from breaking down too quickly, enhance pharmacokinetic characteristics, and enable regulated and prolonged drug release. There is mounting evidence that biodegradable polymers like PLGA, chitosan, and PEG are safe and biocompatible, which lends credence to their use in medicine. To sum up, doxorubicin targeted delivery via surface-modified biodegradable polymeric nanoparticles is an exciting new idea. The use of these nanocarriers may revolutionise cancer chemotherapy as we know it and make great strides toward precision medicine by increasing medication specificity, decreasing systemic toxicity, and boosting therapeutic efficacy. Future cancer treatment options are anticipated to be safer, more effective, more patient-centered as a result of ongoing research and technology advancement in this area.

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